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Research on Control Method for Intermediate Point Temperature of Supercritical Boiler Based on Active Disturbance Rejection Cascade Control

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Abstract

As the important signal of once-through boiler's water-fuel ratio control, intermediate point temperature of supercritical boiler plays a key role in the decision of steam and water's boundary, the match of fuel and water, the control of main steam temperature. The condition of its control directly impacts the once-through boiler's safety and economy running. For an uncertainty model, a good control quality cannot be gained using the general PID controller when the unit load has great changes, so that the main steam temperature fluctuates greatly. According to this problem, a control system about intermediate point temperature of supercritical boiler based on active-disturbances-rejection multiple model was designed. Corresponding active disturbances rejection controller (ADRC) about different model in different operation points was designed. It can choose corresponding controller according to the operation condition so as to achieve an adaptive control of a wide range. The simulation results show that the system has a strong robustness and sufficient capability for control.

Keywords: *supercritical boiler, intermediate point temperature, multiple model, active disturbances rejection controller, robustness*

1. Introduction

As the important signal of once-through boiler's water-fuel ratio control, intermediate point temperature of supercritical boiler refers to the temperature of the working medium in the steam-water separator. At present, the cascade PID controller is often used to control the intermediate point temperature. However, when the unit operates with load changing, the contradiction between the fast and overshoot of the control system will produce because the factors such as relatively large variation range of controlled object's parameter, significant nonlinear effect, the change of characteristics of ash blowing and coal and so on interference. And the contradiction will make the control exist lag, so it is difficult for the control of intermediate point temperature to obtain better effect in a large range of unit load. While the active disturbance rejection controller has better control quality and anti interference ability for a complex system with nonlinear and uncertain disturbance [1-2]. According to this problem, a control system about intermediate point temperature of supercritical boiler was designed based on active disturbances rejection multiple model.

2. Structure of Multi-Model Control System Based on ADRC

The feed-forward control strategy with cascade PID controller is generally adopted by thermal power plant to control the intermediate point temperature of supercritical boiler. The control structure is composed of an outer loop controller, an inner loop controller and a feed-forward controller. The outer loop controller is responsible for the control of intermediate point temperature. The inner loop controller is responsible for controlling the water-feed. The feed-forward controller is responsible for controlling the ratio of fuel-feed and water-feed. The equilibrium between water-feed and fuel-feed can be reached quickly through adjusting the PID link. Since the issues such as the change of coal characteristics, ash deposition of boiler, starting or stopping of the coal grinding machine and so on can appear in the process of

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controlling the intermediate point temperature actually, and the fixed value of intermediate point temperature is changing with the changing of load. Therefore, the traditional PID control method is difficult to meet the control requirements of unit when the power plants operate in different conditions.

In order to improve the controller’s performance when the load changes in a large range, this paper designs a controller combined with ADRC and multi-model based on the traditional PID controller. The outer loop of the controller is composed of a plurality of local active disturbance rejection cascade, and every local ADRC controller is directed to various typical load conditions. When the control system is in operation, the local ADRC controllers give their respective control effects according to the system operation situation, and the actual control effect applied to the controlled object is the weighted sum of every local controller's outputs [3]. The weight coefficient depends on the matching degree of the actual object model and the typical conditions, and its value relates with the model predictions and deviation of actual outputs. The Figure 1 is the Structure of multi-model switching based on ADRC. The "K" is the ratio of fuel-feed and water-feed.

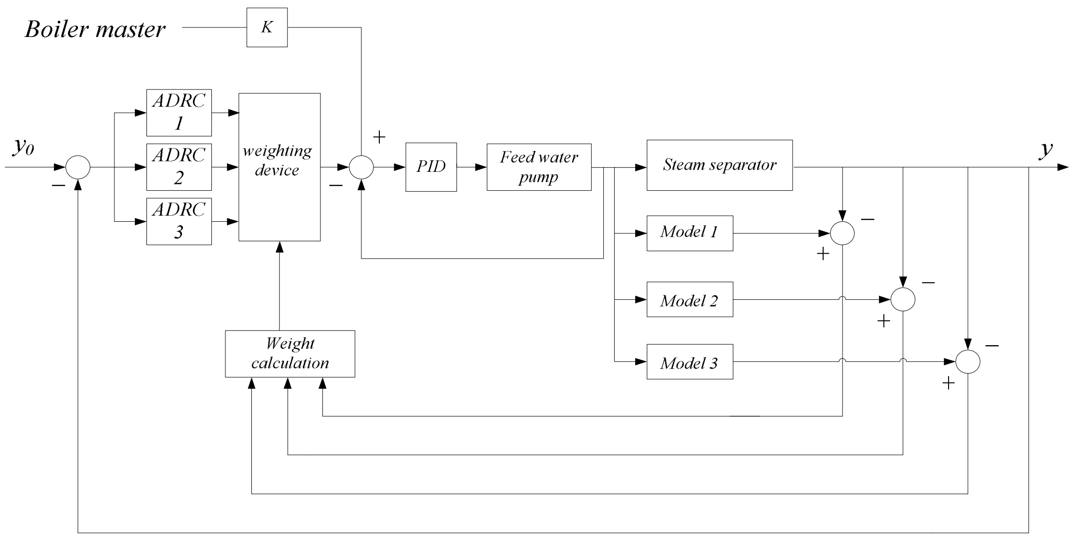

Figure 1. Structure of Multi-model Control System Based on ADRC

3. ADRC Controller Design of the Outer Loop

3.1. Active Disturbance Rejection Controller

Active disturbance rejection controller based on the feedback linearization is a new type controller, which is composed of the tracking differentiator, the extended state observer, and the nonlinear state error feedback. It transforms the nonlinear system into an integral serial structure of a linear system through the nonlinear transformation so as to realize the dynamic feedback linearization. As a result of the ADRC divides objects according to the time scale of controlled system, it is not necessary to consider the linear or nonlinear and the time-varying or time-invariant of the system when the ADRC is designed. Compared with the conventional PID controller, the ADRC has better adaptability and robustness, and overcomes the shortcomings of traditional PID in the contradiction between speediness and stability at the same time.

As a novel type of controller, the ADRC is designed based on feedback linearization. Take two order ADRC as an example to introduce its algorithm [4-6]. The controller structure is shown in Figure 2.

Two order uncertain object:

$$\begin{cases} x_1 = x_2 \\ x_2 = f(x_1, x_2, w, t) + bu \\ y = x_1 \end{cases} \tag{1}$$

The $f(x_1, x_2, w, t)$ contains all the dynamics characteristics of the system such as nonlinear, time-varying parameters and external disturbance etc.

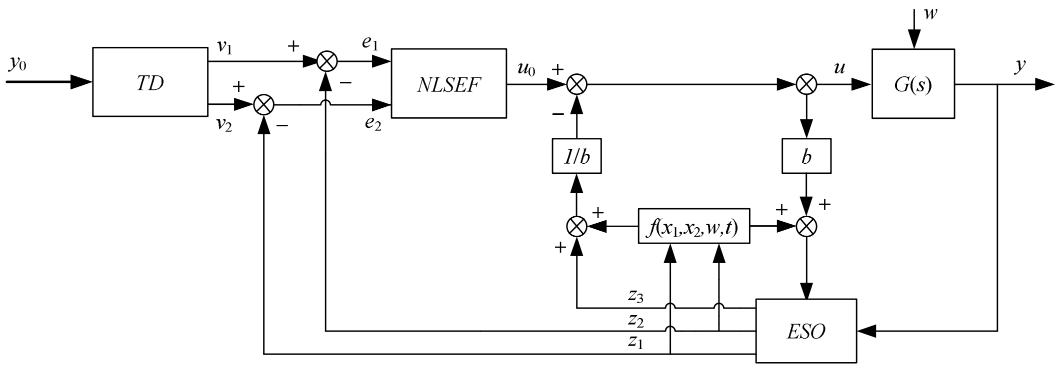

Figure 2. Structure of local ADRC controller at the external loop

3.2. Tracking Differentiator

The working principle of Tracking differentiator (TD) is to produce two signals for a given input signal, each is tracking signal v1 of the given signal y0, and each is differential signal of the given signal y0. At the same time, the TD can give continuous and no overshoot tracking signal for every given continuous or discontinuous signal. The tracking speed depends on the parameters of r, and the bigger of the r, the more quickly of the tracking speed; on contrary, the smaller of the r, the more slowly of the tracking speed.

Take the two order tracking differentiator as an example, whose differential equation can be expressed as follow:

$$\begin{cases} v_1 = v_2 \\ v_2 = \psi, |\psi| \le r \end{cases} \quad (2)$$

In Eq. (2), $f_{st}(v_1, v_2, r, h_0)$—nonlinear function, h_0—filtering factor, r —velocity factor. The expression of$\psi$is as follows:

$$\begin{cases} d = rh_0 \\ d_0 = dh_0 \\ \eta = v_1 - y_0 + h_0 v_2 \\ a_0 = \sqrt{d^2 + 8r|\eta|} \\ a = \begin{cases} v_2 + \eta / h_0, & |\eta| \le d_0 \\ v_2 + [\mathrm{sign}(\eta)(a_0 - d)]/2, & |\eta| > d_0 \end{cases} \\ f_{st} = \begin{cases} -r(a/d), & |a| \le d \\ -r\mathrm{sign}(a), & |a| > d \end{cases} \end{cases} \quad (3)$$

Therefore, the TD not only can pretreatment the given signal and arrange the transition process, but also can extract continuous and differentiable signal from a nondifferentiable signal or noise signal in a reasonable way.

3.3. Extended State Observer

Three order extended state observer (ESO) equation:

$$\begin{cases} \varepsilon = z_1 - y \\ z_1 = z_2 - \beta_{01}\, fal(\varepsilon, \alpha_1, \delta) \\ z_2 = z_3 - \beta_{02}\, fal(\varepsilon, \alpha_2, \delta) + bu \\ z_3 = -\beta_{03}\, fal(\varepsilon, \alpha_3, \delta) \end{cases} \tag{4}$$

In Eq. (4), u— input signal of The object; y — output signal of the object; β_{01} 、β_{02} 、β_{03} — observer coefficient; $0<k\leq 1$; $f_{al}(\varepsilon,\alpha_k,\delta)$ (k=1,2,3) — nonlinear function.

$$f_{al}(\varepsilon, \alpha_k, \delta) = \begin{cases} \dfrac{\varepsilon}{\delta^{1-\alpha_k}}, & |\varepsilon| \leq \delta \\ |\varepsilon|^{\alpha_k}\, \mathrm{sign}(\varepsilon), & |\varepsilon| > \delta \end{cases} \tag{5}$$

The output signal of ESO is an estimation signal for internal disturbance and external disturbance of the controlled object. As an independent extended state observer of the controlled object and the external disturbance, the ESO can give a satisfactory estimation signal as long as the parameters β_{01}、$\beta_{02}$and $\beta_{03}$are chosen reasonably.

3.4. Control Law of Nonlinear State Error Feedback

The tracking signal v1 and differential signal v2 generated by TD compared with the state estimation signal generated by ESO to form two error amounts:

$$\begin{cases} e_1 = v_1 - z_1 \\ e_2 = v_2 - z_2 \end{cases} \tag{6}$$

Then select the appropriate nonlinear function according to the two error amounts to produce u_0 :

$$u_0 = \beta_1 f_{al}(e_1, \alpha_1, \delta) + \beta_2 f_{al}(e_2, \alpha_2, \delta) \tag{7}$$

The Eq. (7) is called the control law of the nonlinear state error feedback. Then according to the interference estimate signal z_3 given by ESO and the known part of the controlled object, it can form the control volume u:

$$u = u_0 - z_3 / b \tag{8}$$

4. Multi-Model Control's Switching Strategy of the Water Level of a Steam Generator

The controller of the external ring needs to be switched when the load power of the system changes. At each sampling time, the controller's weights of the local model will be adjusted according to the matching error of the model output and the actual output as the performance index of the system [7-8].

In the process of system operation, the matching error of the predicting output $z_{1i}(k)$(i=1,2,…,n) of n local models and the actual output $y(k)$ of the controlled object in the k sampling time can be expressed as the following:

$$e_i(k) = \frac{|z_{1i}(k) - y(k)|}{|y(k)| + \sigma} \tag{9}$$

In Eq. (9), δ is a constant ($0<\delta\leq 1$). The sum of the matching error within a period of time t is given by

$$e_i(k,t) = \sum_{n=k-t}^{k} \frac{|z_{1i}(n) - y(n)|}{|y(n)| + \sigma} \tag{10}$$

In Eq. (10), t is the rolling cumulative length of the matching error, and it usually is the max modeling's length. Therefore, the recursion formula of the matching error can be gotten:

$$e_i(k,t) = e_i(k-1,t) + \frac{|z_{1i}(n) - y(n)|}{|y(n)| + \sigma} - \frac{|z_{1i}(k-t-1) - y(k-t-1)|}{|y(k-t-1)| + \sigma} \tag{11}$$

In order to reduce the importance of historical information, the paper introduces the forgetting factor λ(0<λ<1) of matching error and gets the equation as follows, in which, accumulated value $e_i(0,t)=0$,

$$e_i(k,t) = \lambda e_i(k-1,t) + \frac{|z_{1i}(n) - y(n)|}{|y(n)| + \sigma} - \lambda^{t+1}\frac{|z_{1i}(k-t-1) - y(k-t-1)|}{|y(k-t-1)| + \sigma} \tag{12}$$

The outputs of main controller's outer ring use the every local controller's weighted sum, each local controller output weight computing method for. The output weight of every local controller can be computed as follows:

$$\bar{\mu}_i = \begin{cases} 1, e(k,t) = e_i(k,t) \\ 0, e(k,t) \neq e_i(k,t) \end{cases} \tag{13}$$

In Eq. (13)

$$e(k,t) = \min\{e_1(k,t), e_2(k,t), ..., e_n(k,t)\} \tag{14}$$

Narendra K S [9] has proved different switching scheme does not influence the stability of the system, and the system is globally stable as long as every controller is used alone. Therefore, in order to ensure the stability of the switching algorithm, the closed loop system composed of each object model and the corresponding controller is stability.

5. Intermediate Point Temperature Control System Simulation

5.1. Dynamic Characteristics of Intermediate Point Temperature on Water and Fuel Disturbance

It is different for the transfer function of intermediate point temperature process due to feedwater flow and coal specific consumption disturbance under different load [10-13]. The transfer functions listed in Table 1 can be obtained using the method of measure of area according to the step response curve.

Table 1. Transfer function of intermediate point temperature process due to feedwater flow and coal specific consumption disturbance under different load

Working conditions	Transfer function due to feedwater flow disturbance	Transfer function due to coal specific consumption disturbance
BMCR /(/%)	$-\frac{0.26}{(24.94s+1)(8.91s+1)}$	$\frac{0.80}{(19.81s+1)(4.79s+1)}$
75%BMCR /(/%)	$-\frac{0.31}{(29.03s+1)(18.63s+1)}$	$\frac{1.36}{(30.92s+1)(3.30s+1)}$
50%BMCR /(/%)	$-\frac{0.59}{(33.24s+1)(7.38s+1)}$	$\frac{3.09}{(24.69s+1)(13.22s+1)}$

5.2. Simulation of Control System and Result Analysis

In the process of simulation, the system's model is established using simulink in MATLAB, whose toolbox can be applied to edit the ADRC controller. The algorithm of the ADRC can be edited using S function and be used to set appropriate parameters [14]. In the simulation, the baseline value of benchmark signal about feedwater disturbance is 1. With the coal specific consumption disturbance given at t=300s, the comparison between the ADRC and the PID controller shows an improvement in different power points. The simulation result is shown in figure 3, 4, 5, 6. The results show that: the ADRC controller has a good control effect on the intermediate point temperature and has strong adaptability and robustness on the uncertainty and external disturbance of control system. The nonlinear structure used by ADRC can overcome the inherent defects of the traditional PID control fundamentally, and can effectively solve the problem such as uncertainty of object model, more disturbance and time lag and so on [15]. It can be seen from the simulation curve that: in the different loads, the ADRC controller can make a quick response so as to make the outputs in the ideal range when the load changes. Thus it achieves the purpose of improving control effect of the system.

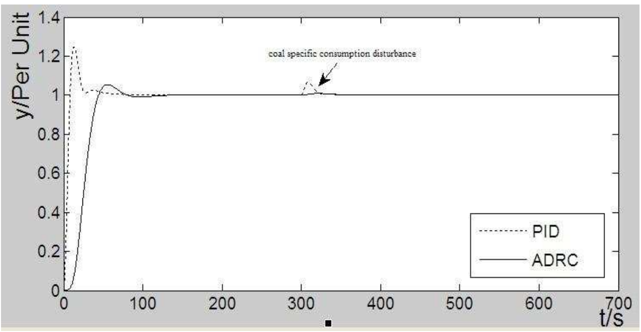

Figure 3. Curves of intermediate point temperature's emulation due to feedwater disturbance and fuel disturbance at BMCR

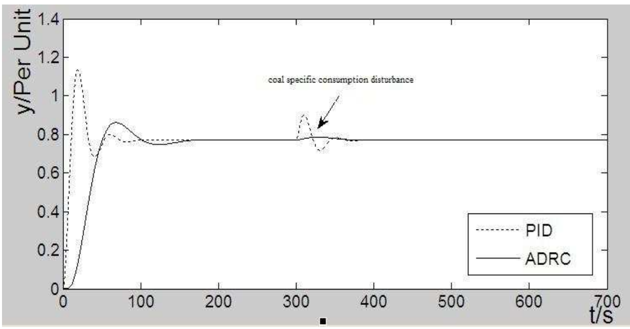

Figure 4. Curves of intermediate point temperature's emulation due to feedwater disturbance and fuel disturbance at 75% BMCR

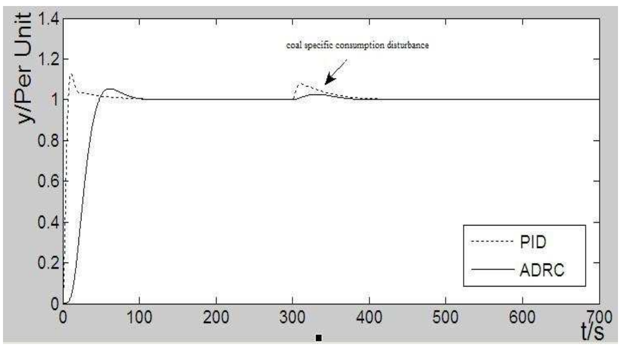

Figure 5. Curves of intermediate point temperature's emulation due to feedwater disturbance and fuel disturbance at 50% BMCR

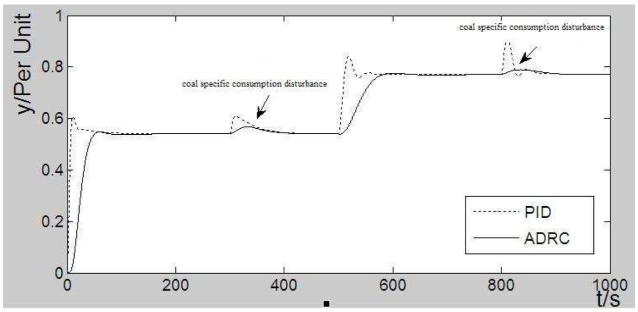

Figure 6. Curves of intermediate point temperature’s emulation due to feedwater disturbance and fuel disturbance at 50%~75% BMCR

6. Conclusion

Combined with multiple model control, the ADRC using ESO to estimate various disturbances is applied to control system of intermediate point temperature. In addition, the controller improves effectively the anti interference and adaptive ability of intermediate point temperature control by the disturbance's compensation of feed-forward. Thus it provides a new train of thought to water level control for SG in nuclear power plant.

Through the logic designs, the system can complete the control task of feed water of supercritical boiler together with other control methods.

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